Geologic Map of the Cañoncito School 7.5-Minute Quadrangle, Bernalillo and Cibola Counties, New Mexico

By

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Open-file Digital Geologic Map OF-GM 281

Scale 1:24,000

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Executive Summary

The Cañoncito quadrangle is 25 miles west of Albuquerque along Interstate 40 on the west flank of the Rio Puerco Valley in central New Mexico. The community of Cañoncito is in the northwest corner of the quadrangle. The quadrangle encompasses land of the Laguna Pueblo and the To'Hajiilee Navajo Chapter, along with BLM land and minor private inholdings. Development and population are very sparse outside of Cañoncito, consisting only of rural residents on tribal lands.

The bedrock geology consists of shallowly to steeply east- and southeast-dipping Jurassic and Cretaceous sedimentary rocks, with Miocene Santa Fe Group sediments abundantly exposed in in the eastern half. The Jurassic Todilto Formation, Summerville Formation, Bluff Sandstone, and the Brushy Basin and Salt Wash Members of the Morrison Formation are exposed along the faulted bluffs of Herrera Mesa on the western side of the quadrangle. The Cretaceous rocks include multiple intertongueing intervals of Dakota Sandstone and Mancos Shale, overlain by the Gallup Sandstone, the Dilco Member, the Dalton Sandstone, and the Gibson Coal Member of the Crevasse Canyon Formation, and the Point Lookout Sandstone and Menefee Formation of the Mesaverde Group. The Santa Fe group sediments comprise the Piedra Parada Member, overlying Chamisa Mesa Member, and the upper member of the Zia Formation. The Santa Fe Group occurs with both fault contact and depositional contact on the Menefee Formation.

The Cretaceous and Jurassic rocks are pervasively cut by dip-slip and oblique-slip faults striking north to ≈20° east of north. Sense of motion and amount of displacement vary along many of the longer faults, with both east- and west-side down motion present. Some component of strike-slip motion is likely along many of these faults based on map patterns, apparent offset variations, and limited slickenline data. The east side of Herrera Mesa along the west margin of the quadrangle is an east-side down, faulted monocline. Complex fault networks and steep easterly dips are present in the vicinity of Cañoncito and extend about 5 miles to the south, where dips flatten and displacement appears to be largely on one fault. The presence of a graben east of Herrera Mesa in the southwest corner is suggested by limited bedrock exposures in arroyos, but the fault locations are largely speculative due to cover by surficial deposits and lack of well control. Movement along the faults is probably of Laramide-age, with local reactivation during formation of the Rio Grande rift, during which time the Santa Fe Group sediments were deposited.

Quaternary deposits are abundant, with most upland areas mantled to some degree with loose sand comprising sheets, subdued dunes, and sheetwash deposits. Major drainages have broad, flat floors of dominantly fine-grained alluvial sediment that is incised several meters along the main stream course. Older, higher, and locally coarser alluvium along the margins of larger drainages is present sporadically across the northeast corner of the quadrangle.

Description of Map Units

QUATERNARY

Anthropogenic Deposits Anthropogenic Deposits

afd Artificial fill and related ground disturbance

Recent (<80 years old)

Long—

Excavated sand, silt, and clay that were locally moved. Generally associated with berms, dams, highways, and exploratory drilling projects. The thickness is 1–6 m.

Short—

Excavated sand, silt, and clay that were locally moved. Generally associated with berms, dams, highways, and exploratory drilling projects. The thickness is 1–6 m.

Eolian and Sheetflood Deposits

Qe Eolian sand

Late Holocene to Recent

Long—

Eolian sand on ridge tops or sand ramps on the lee (commonly northeast) sides of ridges or mesas. The deposit is massive. The sand is light-brown to reddish-yellow (7.5YR 6/4–6), fine- to medium-grained, mostly fine-upper to medium-upper (fU–mU), with 0.5–1% scattered coarse sand, mostly subrounded, well-sorted, and composed of quartz, about 10–25% feldspar, and 1–10% lithic and mafic grains. The deposit is loose and 1–3 m thick.

Short—

Eolian sand on ridge tops or sand ramps on the lee (commonly northeast) sides of ridges or mesas. The deposit is massive. The sand is light-brown to reddish-yellow, fine- to medium-grained, mostly fine-upper to medium-upper (fU–mU), with 0.5–1% scattered coarse sand, mostly subrounded, well-sorted, and composed of quartz, about 10–25% feldspar, and 1–10% lithic and mafic grains. The deposit is loose and 1–3 m thick.

Qs Slopewash and sheetflood deposits

Late Pleistocene to Holocene

Long—

Massive sand and clayey–silty sand with local laminations (typically horizontal-planar) or very thin to thin beds (tabular to lenticular). The proportion of pebbly lenses is very low (typically <10%). The sand is brownish, very fine- to medium-grained (up to 5% scattered, coarser sand

grains), subangular to rounded, and well- to moderately sorted. The deposit occupies wide topographic lows at the heads of low-order drainages. It is inferred to be deposited by unconfined flow (i.e., slopewash and sheetflooding). The thickness is 1–6 m.

Short—

Massive sand and clayey–silty sand with local horizontal-planar-laminations or very thin to thin beds. The proportion of pebbly lenses is typically <10%. The sand is brownish, very fine- to medium-grained (up to 5% coarser sand), and well- to moderately sorted. The deposit occupies wide topographic lows near the base of steeper slopes. It is inferred to be deposited by unconfined flow (e.g., slopewash). The thickness is 1–6 m.

Qse Slopewash and sheetflood deposits reworking eolian material

Late Pleistocene to Holocene

Long—

Sand that underlies low-relief, relatively low slope-angle hillslopes. The unit laterally grades with unit **Qes** and **Qasyr**. The sediment consists of vaguely bedded (mostly medium to thick) or massive, fine- to medium-grained sand overprinted by paleosols. The sand is pale-brown to brown (10YR 6/3–5/4), subrounded, and composed of quartz, minor feldspar, and 10–20% lithic grains. The beds are internally massive or locally exhibit laminations (horizontal-planar or low cross-laminations). The paleosols are characterized by ped development, clay illuviation, and variable precipitation of calcium carbonate (mostly stage I to II). The sediment is inferred to be derived largely from reworking of eolian deposits from slopewash or sheetflood processes, with some contribution from older sedimentary rocks. The thickness is 0.5–5 m.

Short—

Vaguely bedded (mostly medium to thick) or massive, fine- to medium-grained sand overprinted by paleosols with stage I to II calcic horizons. The beds are internally massive or locally laminated. The deposit is found on low-relief, low slope-angle hillslopes. It is inferred to be deposited by sheetfloods or slopewash that reworked eolian sand as well as other uphill lithologic units. The thickness is 0.5–5 m.

Qes Eolian sand and high-level sheetflood deposits reworking eolian material

Late Pleistocene to Holocene

Long—

Very fine- to medium-grained sand composed of eolian sand sheets and minor dunes on mesa tops or gently sloping geomorphic surfaces. The looser sand near the surface is light-brown to reddish-yellow (7.5YR 6/4–6) to strong-brown (7.5YR 5/6) and mostly fine- to medium-grained, subrounded, well-sorted, and composed of quartz, minor feldspar, and 1–10% lithic-mafic grains.

Very weak to no soil development. Below roughly 0.5–1 m depth, the sediment is in vague, medium to very thick, tabular beds that are overprinted by paleosols, locally burrowed, and internally massive. This deeper sand is slightly finer, very fine-lower to medium-lower (vfL–mL), has 0–10% clay–silt, and is light-brown to reddish-yellow (7.5YR 6/4–6) to yellowish-brown to light-yellowish-brown (10YR 5–6/4). The paleosols exhibit calcium carbonate accumulation with Stage I to II morphology, ped development (weak to moderate, medium to very coarse, subangular to angular blocky to prismatic, slightly to very hard), and distinct but faint or no clay films and bridges. The sand is locally interbedded with thin pebbly lenses. Weakly to moderately consolidated and non-cemented. The thickness can be up to 13 m, but typically 1–6 m.

Short—

Very fine- to medium-grained sand composed of eolian sand sheets and minor dunes on mesa tops or gently sloping geomorphic surfaces. The sand is light-brown to reddish-yellow to strong-brown, subrounded, and well-sorted. The deeper sand is weakly to moderately consolidated and in vague, medium to very thick, tabular beds overprinted by paleosols with stage I to II calcic horizons. The thickness is 1–6 m.

Qseo Older slopewash and sheetflood deposits reworking eolian material

Late Pleistocene to Holocene

Long—

Massive, light-colored, moderately to well consolidated, very fine- to fine-grained sand likely correlating to the deeper parts of unit **Qse**. The sand is light-gray to white (2.5Y 8/1–7/2 and 10YR 7/2), very fine to fine-grained with minor medium-lower (mL) grains, subangular to rounded (mostly subrounded), well sorted, and composed of quartz, minor feldspar, and 5–15% lithic grains. The sediment has 0–5% clay–silt, minor (1–5%) scattered calcium carbonate nodules, and is locally overprinted by weak paleosols. Up to several meters thick.

Short—

Massive, light-colored, moderately to well consolidated, very fine- to fine-grained sand likely correlating to the deeper parts of unit **Qse**. The sand is light-gray to white, very fine to fine-grained, mostly subrounded, and well sorted, The sediment has 0–5% clay–silt, minor (1–5%) scattered calcium carbonate nodules, and is locally overprinted by weak paleosols. Up to several meters thick.

Alluvial Deposits

Qfr Recent alluvial fans at the mouths of gullies

Recent (<80 years old)

Long—

Lobes of sand and gravel deposited at the mouths of gullies. The unit lacks surface soil development and is likely well-stratified. The deposit is loose and 1–3(?) m thick.

Short—

Lobes of sand and gravel deposited at the mouths of gullies. The unit lacks surface soil development and is likely well-stratified. The deposit is loose and 1–3(?) m thick.

Qfyr Younger alluvium forming distinctive alluvial fan deposits

Holocene and Recent

Long—

Similar to unit **Qasyr**, but forms distinctive alluvial fans as seen in aerial imagery. The deposit consists of massive sand with 3–5% scattered pebbles and 1–3% very thin to thin, lenticular, sandy pebble beds. The pebbles are very fine to coarse. The sand is pale-brown to light-yellowish-brown (10YR 6/3-4), moderately sorted, fine- to medium-grained with 5–10% scattered coarse to very coarse sand. The sand is commonly overprinted by weak calcic soils (Stage I morphology). Probably about 5–6 m thick.

Short—

Similar to unit **Qasyr**, but forms alluvial fans as seen in aerial imagery. The deposit consists of massive sand with 3–5% scattered pebbles and 1–3% very thin to thin, lenticular, sandy pebble beds. The sand is pale-brown to light-yellowish-brown (10YR 6/3–4) and fine- to medium-grained with 5–10% scattered coarse to very coarse sand. The sand commonly overprinted by weak calcic soils (Stage I morphology). Probably ≈5–6 m thick.

Qasyr Younger and recent alluvium and sheetflood deposits underlying valley floors

Holocene and Recent

Long—

Sand to clayey–silty sand (it is estimated to contain up to 25% fines). The color of the sand ranges from pale-brown (10YR 6/3) to light-brown (7.5YR 6/4) to brown to light-olive-brown (10YR–2.5Y 5/3) or light-yellowish-brown to very pale-brown (10YR 6–7/4). The sand is massive or in very thin to thick, tabular to lenticular beds that may be internally horizontal-planar-laminated to thinly bedded or, less commonly, cross-laminated. Minor to subordinate (0–40%), lenticular, very thin to medium pebbly beds. The pebbles are clast- to sand-supported, moderately to poorly

sorted, and composed of sandstone (subrounded to subangular) and iron-oxide fragments (angular to subangular) if directly derived from Cretaceous strata or chert, felsic to mafic volcanic rocks, quartzite, quartz, granite, sandstone, or iron-oxide fragments (most to least) if partially derived from units **Tccw** or **Qaorpw**. The sand is very fine- to coarse-grained (mostly fine- to medium-grained with minor scattered coarse and very coarse sand and pebbles) but fine- to very coarse-grained within the pebbly beds. The sand is subangular to rounded, moderately to well-sorted, and composed of quartz, minor feldspar, and 5–15% lithic grains (especially volcanic and chert grains) and lesser mafic grains. There are few to abundant buried soils characterized by subangular blocky ped development and weak calcium carbonate precipitation (Stage I morphology). There is local faint clay illuviation on very few to minor ped faces or as bridges. The top soil is characterized by ped development (up to strong, coarse, prismatic to angular blocky and slightly hard to hard) but typically no clay illuviation and very weak to no calcic horizons. A horizons are common in the upper 10–20 cm (10YR 6/2–3) where there is minimal erosion. Weakly to moderately consolidated and non-cemented (very weak to moderate HCl effervescence). The geomorphic surface is smooth and sandy. There are local lobes of recent alluvium with bar-and swale topography, lower vegetation density, and fresh-looking channels. Up to 6 m of exposed thickness.

Short—

Brownish sand and clayey–silty sand that forms massive or very thin to thick, tabular to lenticular beds (locally horizontal-planar-laminated or cross-laminated). There are minor very thin to medium, lenticular, pebbly beds. The sand is mostly fine- to medium-grained. Buried soils are characterized by ped development and Stage I calcic horizons. Smooth surface except for localized lobes of recent deposition. Up to 6 m of exposed thickness.

Qfo Older alluvial fan deposits

Late Pleistocene to Earliest Holocene

Long—

Sand, pebbly sand, and sandy pebbles in very thin to thick, lenticular to tabular beds. The unit underlies gravelly geomorphic surfaces near the base of steep slopes in the southeast corner of the quadrangle. These surfaces are ≈2 m higher than adjoining **Qfyr** surfaces. The thickness is 1–3(?) m.

Short—

Sand, pebbly sand, and sandy pebbles in very thin to thick, lenticular to tabular beds. The unit underlies gravelly geomorphic surfaces near the base of steep slopes in the southeast corner of the quadrangle. These surfaces are ≈2 m higher than adjoining **Qfyr** surfaces. The thickness is 1–3(?) m.

Qao Older alluvium

Middle or Late Pleistocene

Long—

Sand and pebbly sand interbedded with minor sandy pebbles, silty fine sand, and silt–clay. The sand is light-yellowish-brown (10YR–2.5Y 6/4), pale-brown (10YR 6/3), brownish-yellow to olive-yellow (10YR–2.5Y 5–6/6), light-brown (7.5YR 6/4), or strong-brown to reddish-yellow (7.5YR 5–6/6). The muddy beds are light-brownish-gray to brown (10YR 6/2–5/3). The sand and pebbly sand can be massive within 1–2 m thick beds, horizontal-planar-laminated, or in very thin to thin beds (tabular to lenticular), local low-angle cross-laminations; sandy pebbles are in very thin to thin, lenticular beds. The gravel is composed of very fine- to very coarse pebbles with 0–2% cobbles that are subangular to rounded (mostly subrounded to rounded), moderately sorted, and composed of variable proportions of chert, sandstone, and iron oxide fragments along with minor quartz and quartzite (1–15%), granite (0–15%), petrified wood (0–1%), gray limestone (0–10%), and Tertiary volcanic rocks (1–10%; mainly felsic with minor intermediate volcanic rocks and trace vesicular basalt or basaltic andesite). The sand is fine- to very coarse-grained (mostly medium-grained), subangular to rounded, poorly to well sorted, and composed of quartz, minor feldspar, and 10–25% lithic grains (mostly chert). Weak effervescence in HCl. Weakly to moderately consolidated. 1–10 m thick.

Short—

Sand and pebbly sand with minor sandy pebbles, silty fine sand, and silt–clay. The sand and pebbly sand may be massive or horizontal-planar-laminated to thinly bedded; sandy pebbles are in very thin-thin beds. Pebbles are composed of chert, sandstone, iron oxide fragments, quartz and quartzite, granite, and Tertiary volcanic rocks. Sand is fine- to very coarse-grained. Weakly consolidated. 1–10 m thick.

Qaof Fine-grained older alluvium

Middle or Late Pleistocene

Long—

Sand, silty fine sand, minor silt–clay and very minor pebbles; deposited by tributaries to the Cañada de Ojo (see description for **Qaot**) but also contains eolian sand intervals. The eolian sand is light-yellowish-brown (10YR 6/4), mostly fine-grained, well-sorted, and relatively clean (lacks silt–clay). Weakly consolidated. 1–10 m thick.

Short—

Sand, silty fine sand, minor silt–clay and very minor pebbles; deposited by tributaries to the Cañada de Ojo (see description for **Qaot**) but also contains eolian sand intervals. The eolian sand

is light-yellowish-brown (10YR 6/4), mostly fine-grained, well-sorted, and relatively clean (lacks silt–clay). Weakly consolidated. 1–10 m thick.

Qaoco Older alluvium deposited by Cañada de Ojo

Middle or Late Pleistocene

Long—

Sand interbedded with subordinate sandy pebbles and pebbly sand. Gravelly intervals are up to 1(?) m thick and laminated to thinly bedded (lenticular or cross-stratified). The gravel are moderately to poorly sorted and consists of very fine to very coarse pebbles. The pebbles are composed mainly of sandstone (subrounded to subangular) and iron oxide fragments (subangular) with 0.5–4% felsic to intermediate volcanic rocks, trace to 1% vesicular basaltic rocks (subrounded to subangular), trace to 18% chert and quartzite (subrounded to rounded), 0–10% granite, 0.5–1% quartz, and 0 to trace Pedernal Chert. There are trace to 5% cobbles composed mainly of sandstone with lesser vesicular basaltic rocks, 0.5–5% granite, and 1–5% quartzite. The sand is yellowish-brown to pale-brown to very pale-brown to light-olive-brown (2.5Y–10YR 5–7/4; 10YR 6/3), fine- to very coarse-grained, subangular to subrounded, moderately to poorly sorted, and composed of quartz, minor feldspar, and 10–20% lithic grains. The deposit is capped, perhaps interbedded, with eolian sand that is light-yellowish-brown (10YR 6/4), fine-grained, well sorted, and relatively massive. The unit is inferred to interfinger locally with side-stream derived, older alluvium (**Qao**). Loose to weakly consolidated. At least 4 m thick, thinning away from Canada de Ojo.

Short—

Sand interbedded with subordinate sandy pebbles and pebbly sand that are laminated to thinly bedded (lenticular or cross-stratified). The pebbles composed mainly of sandstone and FeO fragments. The sand is tan and fine- to very coarse-grained. The unit may interfinger locally with side-stream derived alluvium (**Qao**). Fine sand near top. Weakly consolidated. At least 4 m thick, thinning away from Cañada de Ojo.

Qaocoh High-level older alluvium deposited by the Cañada de Ojo

Middle or Late Pleistocene

Long—

Sand with variable gravel that lies above unit **Qaoco**. The gravel consists of very fine to very coarse pebbles with 1–5% cobbles that are subangular to subrounded. The gravel are composed mostly of tan sandstone and iron oxide fragments (siderite) with 1–3% mafic rocks, 0.5–10% chert, 0.5–5% quartz, and trace to 3% petrified wood. 1–8 m thick.

Short—

Sand with variable gravel that lies above unit **Qaoco**. The gravel consists of very fine to very coarse pebbles with 1–5% cobbles that are subangular to subrounded. The gravel are composed mostly of tan sandstone and iron oxide fragments (siderite) with 1–3% mafic rocks, 0.5–10% chert, 0.5–5% quartz, and trace to 3% petrified wood. 1–8 m thick.

Qaorpw Older alluvium of the Rio Puerco and associated western tributaries

Early(?) to Middle Pleistocene

Long—

Pebbly sand and sand interbedded with subordinate sandy gravel and very minor beds of fine sand or muddy fine sand. The strata are in very thin to thin (minor medium to thick), tabular to lenticular beds; sand beds are internally horizontal-planar-laminated; local cross-stratification (planar foresets up to ≈50 cm tall). The gravel consist of very fine to very coarse (mostly very fine to coarse) pebbles, 1–5% cobbles and 0–0.5% boulders. The gravel is subangular to rounded (mostly subrounded to rounded), that are moderately to poorly sorted within a bed and are composed of 20–50% multicolored chert, 1–40% brown to tan to yellow to red sandstone (mainly Mesozoic), 1–5% quartz, 1–3% quartzite, 0–10% felsic tuffs and volcanic rocks, 1–10% red granite and granitic gneiss, 1–20% intermediate to basaltic andesite rocks, 0.5–5% basaltic rocks, 1–15%% iron-oxide fragments, 0–5% petrified wood, trace Pedernal Chert, and trace Paleozoic limestone. The cobbles and boulders are composed mainly of sandstone and vesicular basalt, with minor granite and quartzite. The sand is light-yellowish-brown to very pale-brown (10YR 6/4–7/3) to pale-brown (10YR 6/3), with local strong-brown (7.5YR 5/6), fine- to very coarse-grained (mostly medium to coarse), subangular to rounded (mostly subrounded), moderately to poorly sorted, and composed of quartz, minor feldspar, and 10–35% lithic grains (i.e., chert and lesser volcanic, siderite, granite, and sedimentary grains—most to least abundant). Local paleosols near base of unit exhibiting reddish hues, calcium carbonate precipitation (generally as nodules), and moderate, fine to coarse, subangular blocky ped development. Weakly to moderately consolidated; non-cemented except for very minor strong cementation in 1–30 cm thick intervals, particularly at the base of the unit (where cementation may be up to 3 m thick). About 4–5 m above the base of the deposit is a 30–100 cm thick, white, fine ash correlative to the Lava Creek B ash. 3–30 m thick.

Short—

Pebbly sand and sand interbedded with subordinate sandy pebbles. Sand is light-yellowish-brown to very pale-brown and fine- to very coarse-grained. The pebbles are composed of chert and sandstone with 1–10% quartz and quartzite, 1–10% red granite, 1–20% intermediate to basaltic andesite rocks, 0.5–5% basaltic rocks, and 1–15%% FeO fragments. Contains Lava Creek B ash. Weakly consolidated. 3–30 m thick.

CENOZOIC BASIN FILL OF THE SANTA FE GROUP

Cerro Conejo and Arroyo Ojito Formations

Tccw Cerro Conejo Formation, western-derived deposits

Middle to Late Miocene

Long—

Orangish sand interbedded with subordinate (10–25%) pebbly intervals dominated by chert clasts. The sand occurs mainly in medium to very thick (mostly thick), tabular beds that are yellowish-red to reddish-brown to strong-brown (5YR 5/6, 7.5 5/6) to light-brown (7.5YR 6/4), with minor brownish-yellow (10YR 6/6) or pink to very pale (7.5–10YR 7/3–4). Sand typically contains minor (0.5–10%) scattered pebbles and the beds are internally massive or horizontal-planar-laminated. Local paleosols are redder in color, have weak to moderate ped development, and minor (Stage I to I+) calcium carbonate precipitation. The sand is mostly fine-upper to medium-upper (fU–mU) but ranges from fine-lower to very coarse-grained (very coarse-grained is mostly associated with pebble beds), subrounded (minor subangular), moderately to poorly sorted, and composed of quartz, minor [10–30(?)%] feldspar, and 15–25% lithic grains (chert and lesser volcanic grains). The pebbly intervals are composed of very thin to thin, tabular to lenticular beds of sand (internally horizontal-planar-laminated) interbedded with subordinate sandy pebbles in very thin to thin, tabular to lenticular beds. The pebbles are fine to very coarse in size, mostly subrounded to well-rounded (except for felsic tuffs, which are relatively angular), moderately to poorly sorted, and composed of multi-colored chert, 3–15% quartz and quartzite, and 15–25% volcanic clasts; no granite gravel is present. Volcanic clasts are mostly felsic tuffs with only minor intermediate volcanic types. Minor light-yellowish-brown (10YR 6/4), massive, fine- to medium-grained, well-sorted, subrounded to subangular sand inferred to be eolian. Greenish beds (1–2%) composed of mudstone or muddy very fine- to fine-grained sandstone. Very minor clayey, tabular beds that are light-brown to brown (7.5YR 6/3–4) and mixed with variable proportions of sand. Weakly to moderately consolidated and non-cemented. >60 m thick.

Short—

Light-orangish sand interbedded with 10–25% pebbly intervals. Sand beds typically contain 0.5–10% scattered pebbles and are thick, tabular, and internally massive to horizontal-planar-laminated. Pebbles are composed of chert, 3–15% quartz and quartzite, and 15–25% volcanic clasts dominated by felsic tuffs. Very minor beds of clayey sand. Weakly to moderately consolidated and non-cemented. >60 m thick.

Ton Navajo Draw Member of the Arroyo Ojito Formation

Middle to Late Miocene

Long—

Tan to pink, well-bedded sand interbedded with subordinate beds of silty fine sand and clay. The sand is in very thin to medium, tabular beds with well-defined internal laminations (horizontal-planar- or cross-laminated, the latter including ripple marks). Clayey beds are thin to thick, tabular, and internally massive. There are minor, very thin to thin (up to 20 cm thick) medium to very coarse sand or sandy pebble beds similar to those in unit **Tccw**. The sand is very pale-brown to pink (7.5–10YR 7/3) or light-gray (10YR 7/2), very fine- to medium-grained, subrounded to subangular, moderately to well sorted, and composed of quartz, minor feldspar, and 10–25% lithic grains (chert, volcanic, granite) plus 1–5% mafic grains. The clayey beds are light-brown to brown (7.5YR 4–6/3) to pinkish-gray (7.5YR 6/2), and either pure or mixed with sand. There are trace to 5% pebble-size calcium carbonate nodules. The sediment was deposited on a basin floor by a southward-flowing drainage inferred to be the ancestral Rio Puerco. Weakly to moderately consolidated and non-cemented. Occurs as a 5–10 m thick tongue within unit Tccw.

Short—

Tan, well-bedded sand with subordinate beds of silty fine sand and clay. The beds are very thin to thick, tabular and the sand beds are laminated (horizontal-planar- or cross-laminated). The sand is very fine- to medium-grained and well-sorted. The clayey beds are brown and may be mixed with sand. The sediment was deposited on a basin floor by a southward-flowing ancestral Rio Puerco. Occurs as a 5–10 m thick tongue within unit **Tccw**.

Zia Formation

Tzu Upper Zia Formation

Early or Middle Miocene

Long—

Tabular-bedded, pink to tan sandstone with sparse greenish beds and pastel colors with 1–3% reddish-brown mudstone beds. The strata are in thin to thick, (mostly thick), tabular beds that are internally horizontal-planar-laminated to very thinly bedded. The sandstone beds are either relatively fine-grained (ranging from very fine- to medium-grained) or medium-grained (ranging from fine-upper to coarse-lower). The sand is pink to very pale-brown (7.5–10YR 7/3) to pale-brown (10YR 6/3), subrounded to rounded, well sorted, and composed of quartz, minor feldspar, and 10–25% chert-dominated lithic grains. Approximately 5% medium to thick, tabular, strongly cemented sandstone beds. Clay beds are reddish-brown (2.5YR 5/4) to strong-brown (7.5YR 4/6). Unit includes a pastel-colored sandstone interval several meters thick, trace to 1% greenish sand beds, and trace to 1% fresh-water limestone beds (white to gray). This unit differs from the underlying Chamisa Mesa Member (**Tzcm**) or Piedra Parada Member (**Tzpp**) by slightly coarser

average sand size (more medium-grained), local pastel colors and greenish sand beds, more abundant reddish-brown claystones, and better-defined lamination within thicker beds. Moderately to well consolidated. >20 m thick.

Short—

Pink to tan sandstone with sparse pastel colors and 1–3% reddish-brown mudstone beds. The strata are in thin to thick, tabular beds that are internally horizontal-planar-laminated to very thinly bedded. The sand size ranges from very fine-lower- to coarse-lower-grained. The unit includes a pastel-colored sandstone interval several meters thick, ≤1% greenish sand beds, and ≤1% limestone beds. >20 m thick.

Tzcm Chamisa Mesa Member of the Zia Formation

Early Miocene

Long—

Pink to very pale-brown sandstone, silty sandstone, and 1–10% siltstone in medium to thick (mostly thick-bedded, up to 1.5 m), tabular beds that are internally massive, bioturbated (with paleoburrows), or horizontal-planar-laminated. There are minor intervals (few meters thick and ≈5% of unit) of sandstone that are cross-stratified (forests up to 30 cm tall). Another minor (≈1% of sediment volume) and distinctive lithofacies consists of ≈1 m-thick intervals comprised of 0.5–1.0 cm thick, laterally extensive, tabular beds of sandstone that are commonly strongly cemented. The sand is pink to reddish-yellow (7.5YR 7/3–4 to 6/6) to very pale-brown (10YR 7/3–4), very fine- to medium-grained (mostly fine-lower- to medium-lower-grained), subrounded, well to moderately sorted, and composed of quartz, 10–20% feldspar, and 10–20% chert and orangish quartz, and 3–15% volcanic lithics. Locally, there is up to 10% medium-upper- to coarse-lower-grained sand similar to that seen in the Piedra Parada Member (**Tzpp**). Clay–silt content ranges from 0–10%. There are sparse (1–20%) beds that are extensively paleo-burrowed and strongly cemented. Locally, beds contain rhizoliths 2–11 mm wide and several cm long. Strongly cemented beds comprise an estimated 3–10% of sediment volume and are commonly paleo-burrowed; the remainder are mostly weakly cemented and moderately to well consolidated. The top contact is not observed. The base is mapped at the base of the lowest 7.5–10YR 7/3 bed and above common, relatively coarse (i.e., mU–cL) sand grains. The basal contact with Tzpp is not well-exposed. Compared to Tzpp, this unit is pinker, lacks pebble beds, contains very fine sand and clayey–silty sand, and sand grain size is mostly fU–mU rather than fL–mL. 20–25(?) m thick.

Short—

Sandstone, silty–clayey sandstone, and 1–10% siltstone in medium to thick, tabular beds that are internally massive, bioturbated (with paleoburrows), or horizontal-planar-laminated. Minor intervals (few m thick) of cross-stratified sandstone. Compared to **Tzpp**, **Tzcm** is pinker, contains

very fine sand and clayey–silty sand, and sand grain size is mostly fU–mU rather than fL–mL. 20–25(?) m thick.

Tzpp Piedra Parada Member of the Zia Formation

Early Miocene

Long—

Pale-brown to white sandstone interbedded with 1–5% pebbly beds. Sandstone is in thick to very thick, tabular beds that are internally cross-stratified (laminated to very thin foreset beds up to 80 cm tall), massive, or burrowed (paleo-burrows are 1–1.5 cm diameter). The sand is white (7.5YR 8/1) or pale-brown to light-yellowish-brown (10YR 6/3–4), fine to coarse-grained (mostly fine-upper- to medium-upper-grained), subrounded to well-rounded, moderately to well sorted, and composed of quartz, ≈15–20% feldspar, 5–25% orange-stained quartz and orangish chert, and 5–30% dark lithics (volcanics and chert). Trace to 5% very thin to thin beds contain abundant medium-upper- to coarse-upper-grained sand wholly composed of dark chert and lesser dark volcanic lithic grains. The burrowed sandstone tends to be well-cemented. The pebbly intervals include an orangish gravelly interval commonly seen at the base of unit as well as sparse, stratigraphically higher zones (roughly 1 m thick) where sand is interbedded with subordinate, very thin to medium, lenticular to tabular beds of sandy pebbles. The pebbles are very fine- to coarse-grained, subrounded to well-rounded, moderately sorted, and composed of chert, 10% quartz and quartzite, and 5–30% volcanic rocks composed of light-gray to pinkish-light-gray, plagioclase-hornblende dacite or andesite; felsic tuff clasts are very sparse or not present. Where exposed, the basal pebbly zone consists of a ≈1 m-thick, orangish interval of very thin, lenticular pebble beds (very fine- to coarse-grained, subrounded to rounded) interbedded with very thin to thin, tabular beds of sand. The pebbles are subrounded, moderately sorted, and composed of chert and fine-grained rhyolites (possible fine-grained intermediate volcanic rocks). Non-gravel sediment in the basal zone is composed of pink to very pale-brown (7.5–10YR 7/3–4) sand to orangish clayey–silty sand; sand is fine-lower- to medium-lower-grained (with 10–15% medium-upper to very coarse-upper), mostly subrounded, and poorly sorted. The basal contact is wavy (meter-scale relief) and unconformably overlies unit **Kme**. Strong cementation (10–20%), otherwise, weakly consolidated and non- to weakly cemented. Local cigar-shaped, consistently elongated cemented features that likely reflect paleo-ground-water flow (Mozley and Davis, 1996). Compared to unit **Tzcm**, this unit lacks very fine sand & silty–clayey fine sand (except in the basal zone), lacks pink colors, and grain size is mostly fU–mU rather than fL–mL. ≈15 m thick.

Short—

Pale-brown to white sand stone interbedded with 1–5% pebbly beds. The sandstone is in thick to very thick, tabular beds that are cross-laminated, massive, or paleo-burrowed. The sand is fine to coarse-grained (mostly fine-upper to medium-upper). The pebbles composed of chert, 10% quartz

and quartzite, and 5–30% intermediate volcanic rocks. The basal contact is wavy (meter-scale relief) and unconformable. ≈15 m thick.

LATE CRETACEOUS

Kme Menefee Formation

Late Cretaceous

Long—

Fine-grained floodplain deposits interbedded with 15–30% sandstone channel-fills. Locally hosts abundant petrified wood or logs. The floodplain sediment consists of mudstone, siltstone, and very fine- to fine-grained sandstone. The mudstone is mostly light-gray to gray to grayish-brown to dark-grayish-brown (2.5–5Y 6/1; 7/1–2; 7.5–10YR 6/1; 10YR 4–5/2), with subordinate brown (7.5YR 4–5/2–3) to reddish-brown (5YR 4–5/3). In contrast to unit **Kcg**, the mudstones of this unit are locally greenish-gray (≈5% of unit; 5Y 7/2–3). The mudstone is laminated to very thin, tabular- to wavy-bedded within medium to very thick, tabular beds. Interbedded in the mudstone are minor, thinly bedded, very fine- to fine-grained sandstones that likely represent crevasse splay deposition; these are lenticular to broadly lenticular (1:10 height: width ratio) and commonly white. Also interbedded in the floodplain deposits are coal beds, commonly 10–50 cm thick; these decrease in abundance up-section (1–5% in lower ≈60 m, trace to 0.5% higher in the section). In the mudstone are 0–0.5% organic fragments (up to 6 mm long) and twig or wood imprints. The sandstone in the floodplain deposits is commonly horizontal-planar-laminated. There are local layers with high concentrations of iron oxide concretions, ranging from nodule to boulder-size or occurring in lenses. Also, local orange to yellow discolorations (associated with sulfur?) occur as splotches or in thin layers. Local white ashes up to 15 cm thick are most common lower in the unit. Sandstone channel fills range in size from ribbon forms (0.2–1.5 m thick and ≤ 5 m wide) to broadly lenticular amalgamated bodies (1–6 m thick and up to ≈60 m wide). Channel-fills display trough cross-lamination (up to 30 cm) to tangential cross-lamination (foresets may also be very thin) to horizontal-planar-laminations; also locally massive or in very thin to medium, tabular beds. Measurement of the geometry of the troughs indicate a general northeast paleoflow direction. The sandstone is white to light-gray to very pale-brown (2.5Y 7/1; 10YR 7/3–8/2), weathering to very pale-brown and yellow (10YR 7–8/3; 6–7/6) to light-yellowish-brown to pale-brown to brown (10YR 6/3–4; 5/3). Sand grains are very fine- to medium-grained, subrounded to subangular, well-sorted, and composed of quartz, 5–10% feldspar, and 5–15% black to dark-gray lithic and mafic grains. Trace very fine to medium pebbles composed of iron oxide-cemented, intraformational sandstone. Trace to 1% organic or coal fragments. Ripple marks are locally seen. Variably cemented by calcium carbonate and possibly clay. Preserved thickness is ≈550 m; the original top contact of the formation has not been observed.

Short—

Fine-grained floodplain deposits with subordinate sandstone channel-fills (thick to very thick, ribbon forms or amalgamated, broadly lenticular bodies) that are commonly cross-stratified. Floodplain sediment composed of grayish mudstone, siltstone, and very fine- to fine-grained sandstone; 0.5–2% coal beds. Local petrified wood and fragmented iron oxide concretions. Thickness is ≈550 m.

Crevasse Canyon Formation and Point Lookout Sandstone

Kcus Upper sand-dominated unit in the Crevasse Canyon Formation

Late Cretaceous

Long—

Sandstone-dominated unit that conformably overlies the fine-grained dominated, dark-colored Gibson coal member. Sand bodies are typically 2–10 m thick and in tabular, thin to thick beds; these beds are internally massive, horizontal-planar-laminated, or cross-laminated. Sand is white to yellowish to tan (2.5Y 8/2–7/3–6/4), fine- to medium-grained, subrounded to subangular, well sorted, and has 5–10% mafic-lithics. Local pale-brown (10YR 6/3), calcareous sandstone beds are thick, tabular, and laterally extensive. The sandstone is weakly to well-cemented but exhibits no HCl effervescence (except for the pale-brown, calcareous sandstones). There are subordinate mudstones and very fine-grained sandstones similar to those seen in the Gibson coal member; these occur in 1–3 m thick intervals. Possibly correlative to the Point Lookout Sandstone, cross-section is drawn assuming this is the case and unit is labelled as **Kcus+Kp**. 30–85 m thick.

Short—

Sandstone-dominated strata overlying the predominately fine-grained strata of **Kcg**. Sandstone bodies are typically 2–10 m thick and in tabular, thin to thick beds that are internally massive, horizontal-planar-laminated, or cross-laminated. The sand is white to yellowish to tan and fine- to medium-grained. Subordinate mudstones and very fine-grained sandstones similar to those in **Kcg** are present. Possibly correlative to the Point Lookout Sandstone, cross-section is drawn assuming this is the case and unit is labelled as **Kcus+Kp**. 30–85 m thick.

Kpu Upper Tongue (Main Body) of the Point Lookout Sandstone

Late Cretaceous

Long—

White (locally yellowish or brownish), cliff-forming sandstone. Sandstone is laminated (minor 3–10-cm-thick beds), and cross-stratified (foresets up to 1 m tall) or horizontal-planar-laminated. Very minor (1–5%) 10–100-cm-thick beds that are internally massive. The sand is fine-upper- to medium-upper-grained, subangular, well-sorted, and composed of quartz, 15–20% feldspar (commonly weathering to white), and 10–15% lithic grains (black, gray, or reddish-brown). Local

(<1%) fine-grained intervals consist of mudstone, intimately interbedded shale and fine sandstone, or laminated, fine-grained sandstone containing abundant clay rip-ups. The mudstone is brown to pinkish-gray (7.5YR 5–6/2) and poorly to moderately fissile. These fine-grained intervals pinch out laterally, grading laterally into a laterally extensive and prominent bedding plane. The lower contact of the unit is sharp and planar or exhibits scour relief (up to 1 m). Moderately to well-cemented. Unit description is from the Herrera quadrangle to the north. Identification of this unit in disconnected outcrops in the southwest portion of the quadrangle is tentative. Thickness is ≈60 m

Short—

White, cliff-forming sandstone that is cross-stratified (foresets up to one m tall) to horizontal-planar-laminated. Sand is mostly fine-upper- to medium-upper-grained and subangular. Locally (<1%), there are laterally discontinuous, fine-grained intervals consisting of horizontal-planar-laminated mudstone or clayey fine sand. The lower contact is sharp and scoured. Moderately to well-cemented. The thickness is ≈60 m. Unit description and thickness from the Herrera quadrangle to the north. Identification of this unit in disconnected outcrops in the southwest portion of the quadrangle is tentative.

Kph Hosta Tongue of the Point Lookout Sandstone

Late Cretaceous

Long—

Tongue of white to light-gray (2.5Y 7/1) to yellow (2.5Y 8/2–3) sandstone that is fine- to medium-grained (mostly fine-lower- to medium-lower-grained), subangular, well sorted, and composed of quartz, minor feldspar, and 2–15% dark lithic or mafic grains. Locally near Mesita Blanca in the Herrera quadrangle, midway up in the sandstone tongue is a 10–300 m thick interval of pinkish-gray to gray, clayey–silty fine- to medium-grained sandstone (bioturbated) or interbedded sandstone–mudstone. Tabular beds and bioturbation are more common in lower half of tongue, and cross-stratification is somewhat more abundant in the upper half (foresets are tangential and up to 30 cm tall). Local burrows in the lower half are up to 7 mm wide and 20 cm long. The basal contact is commonly a scoured surface, but also locally gradational (beneath scour) over 1–20 cm. Uppermost 70–80 cm of **Kph** is bioturburbated, with the degree of bioturbation increasing up-section; within 10–20 cm below the upper contact the sandstone is oxidized (orange-reddish) and burrowed. The top surface makes a prominent bench. The unit is moderately to well cemented and forms ledges. The unit description and thickness from the Herrera quadrangle to the north. Identification of this unit from sparse outcrops in a deeply incised arroyo found in the extreme southwest portion of the quadrangle is tentative. Generally 6–8 m thick, but locally pinches out (i.e., NW of Mesita Blanca in the Herrera quadrangle) or is as much as 12 m thick.

Short—

Tongue of white to light-gray to yellow, fine- to medium-grained sandstone that forms a ledge above **Kcg**. Tabular beds and bioturbation are more common in the lower half, and cross-stratification is more abundant in the upper half (foresets up to 30 cm tall). The top surface makes a bench, and within 10–20 cm below the upper contact the sandstone is orange-red and burrowed. The unit description is from the Herrera quadrangle to the north. Identification of this unit from sparse outcrops in a deeply incised arroyo found in the extreme southwest portion of the quadrangle is tentative. Generally 6–8 m thick (locally up to 12 m).

Kcg Gibson Coal Member of the Crevasse Canyon Formation

Late Cretaceous

Long—

Fine-grained deposits, interpreted as swamp and floodplain facies, interbedded with subordinate sandstone channel bodies (paleochannels and crevasse splays). The fine-grained deposits display an overall dark-gray color, contrasting notably with the underlying Dalton Sandstone (**Kcda**) and Mulatto Tongue of the Mancos Shale (**Kmmu**). There are 10–25% sandstone bodies, which are up to 5 m-thick and lenticular over distances of 100s of meters, but also occur as thick, tabular beds. Internally, channel-fills are cross-stratified, with tangential foresets or trough cross-laminations being especially common, or horizontal-planar-laminated. Locally, evidence of bioturbation is observed, such as burrows. Crevasse splay bodies are thin to thickly, tabular bedded (internal horizontal-planar-laminations or locally low-angle cross-laminated) and have scoured or transitional bases with underlying floodplain or swamp facies (the transition is characterized by interfingering of sandstone and the fine-grained deposits, where the proportion of sandstone interbeds increases in proportion up-section). The sandstone beds typically have gradational tops (over 2–3 cm) and locally fine upward. The sandstone (channel fills or crevasse splays) is light-gray to white to tan (10YR 8/2; 2.5Y 7/3–6/4) and fine- to medium-grained, subrounded to subangular, well-sorted, and composed of quartz, ≈3–25% feldspar, and 3–15% mafic and very dark lithic grains. The sandstone locally has a fine-grained matrix, giving it a "dirty" appearance. Also, organic films may coat lamination planes, there is trace organic detritus, and locally there are orange, splotchy discolorations. The sandstone is weakly to strongly cemented by calcium carbonate. Swamp and floodplain deposits are comprised of mudstone, siltstone, and very fine sandstone with 1–5% coal or organic-rich mudstone beds. The very fine sandstone and siltstone are typically light-colored, but silty mudstone and mudstone are darker (with the silty mudstone having a white outcrop color) and displays the following colors: very dark-gray (5YR 3/1), gray to light-gray (N5/ to N7/ and 7.5YR 6/1), brown (7.5YR 4–5/3–4 and 5–6/2), light-grayish-brown to dark-grayish-brown (10YR 4–6/2), and lesser light-reddish-brown to reddish-brown to pink (5YR 6–7/4; 5YR 4/3–5/2; 7.5YR 7/3). The siltstone and mudstone are horizontal-planar- to wavy to crenulated laminated, variably bioturbated, and locally contain reduction-related, splotchy yellow-green-orange discolorations. 1–20% of floodplain facies strata consist of light-gray (7.5YR

7/1) to white siltstone to fine-lower sandstone in very thin to medium, tabular beds that are internally horizontal-planar- to wavy laminated; these may have ≈1% clayey sand or organic-rich lamina. Trace to 3% scattered organic or coal fragments (≈1–3 mm long) in the sandstone or mudstone. Coal beds are thin to thick (up to 50 cm) and tabular. Local (0.5–3%) iron oxide precipitation (presumably siderite) that are in thin to medium, tabular beds, or 10–30 cm thick layers exhibiting abundant concretionary fragments. The unit conformably underlies the sandstone-dominated strata of unit **Kcus** and overlies the Dalton Sandstone. Thickness is 80–85 m.

Short—

Dark-colored, fine-grained swamp and floodplain deposits with subordinate fine- to medium-grained sandstone bodies up to 5 m thick. Fine-grained deposits contain 1–5% coal or organic-rich mudstone beds but generally consist of mudstone, siltstone, and very fine sandstone having horizontal-planar to wavy laminations. Local FeO (siderite?) precipitation. The thickness is 80–85 m.

Kcda Dalton Sandstone Member of the Crevasse Canyon Formation

Late Cretaceous

Long—

Bipartite, coarsening-upward sandstone body. The lower unit is yellowish and in medium to very thick (up to 6 m), tabular beds that are internally massive with subordinate, vague, horizontal-planar-laminations and lesser low-angle cross-laminations; 1–5% thin to medium (minor thick), tabular beds that are internally massive, burrowed, commonly strongly cemented, and locally have bivalve molds; 0–5% 10–20 cm thick, tabular beds that are internally cross-laminated (up to 20 cm tall and exhibiting tangential and planar foresets); near base of unit, local hummocky ripples up to a few cm tall. The sand is pale-brown to very pale-brown to yellow (2.5Y–10YR 7/3–6), locally weathering to golden colors, very fine- to fine- to medium-lower-grained (mostly very fine-upper to fine-upper), subangular, well-sorted, and composed of quartz-rich sand with 3–5% dark lithic grains. The upper unit is more white and cross-stratified than the lower unit, with subordinate horizontal-planar-laminations; foresets are laminated and up to 0.8 m tall. The sand is light-gray (2.5Y 7/2), fine-upper- to medium-lower-grained, subangular, well-sorted, and composed of quartz, 10–15% weathered feldspar, and 5–7% lithic grains. Well-cemented but lacks effervescence in HCl, so cementing agent is likely silica or clays. In both units are trace to 1%, very thin to thick, tabular beds of pinkish-gray (5–7.5YR 6/2) or brown (7.5YR 5/3) fissile shale (horizontal-planar-laminated). The lower contact of the Dalton Sandstone is characterized by a 4–10 m thick interval of interbedded sandstone and mudstone, where the proportion and thickness of sandstone beds increases up-section. We mapped the lower contact at the top of this transitional interval, above which the proportion of shales is ≤3%. Within this transitional interval, sandstone beds are light-yellowish-brown (10YR 6/4), lenticular to tabular, 30–100 cm-thick, and internally massive to horizontal-planar-laminated or locally hummocky ripple-laminated (up to 3 cm tall); shales are light-brownish-gray (2.5Y 6/2) and horizontal-planar-

laminated to slightly wavy; bed contacts are sharp and planar to wavy (up to 3 cm of relief). The upper contact of the Dalton Sandstone is characterized by a 10–12 m thick intertonguing zone, where the upper contact may be wavy (1–10 m of vertical relief) due to the preservation of dunal paleotopography. Interdune, paleotopographic lows are filled by either fissile, gray to light-gray (7.5–10YR 6/1; 2.5Y 6–7/1) shales or light-gray (2.5Y 7/2) massive to horizontal-planar-laminated sand interbedded with minor very thin to medium beds of gray (7.5YR 5/1), poorly fissile shale; both types of strata are inferred to represent lagoonal facies. Where practical at 1:24,000 scale mapping, these interdunal lagoonal deposits are included in basal **Kcg**. Otherwise, the upper contact is placed at the top of the transition zone: above which the proportion of dark-colored and fine-grained sediment is >30%, or at the base of the lowest fine-grained bed that is >=3 m. Uppermost dunal sands are internally massive (bioturbated) to cross-laminated. The Dalton Sandstone is moderately to strongly cemented, and 27–50 m thick. The unit description is from the Herrera quadrangle to the north.

Short—

Bipartite, coarsening-upward sandstone body. The lower unit is yellowish and in medium to very thick, tabular beds that are internally massive with subordinate, vague, horizontal-planar-laminations. The upper unit is more white and cross-stratified than the lower unit, with subordinate horizontal-planar-laminations; foresets are up to 0.8 m tall. Moderately to well-cemented by silica or clays. 27–50 m thick. The unit description is from the Herrera quadrangle to the north.

Kcdi Dilco Member of the Crevasse Canyon Formation

Late Cretaceous

Long—

Gray to brown sandstone, shale, mudstone and impure coal. The lowermost sandstones are light-gray to grayish-brown (10 YR 6/1–10 YR 5/2) non-calcareous, medium- to fine-grained to silty, moderately to poorly sorted, have a clay-rich matrix, and are dominantly composed of subangular to subrounded quartz grains. The bedding is thin and wavy with flaser beds locally and abundant clay fragments and lenses. These beds form a continuum with very clay-rich, friable, sandy mudstone and very shaley sandstone with generally similar appearance, bedding, and weathering characteristics, though colors of the latter tend to dark-grayish-brown to very dark-brown (10 YR 3/2–10YR 2/2). The fissile shale is gray (10 YR 5/1) to darker brown colors. The thin to very thin coal beds are black and shaley. The uppermost sandstone beds are ledgy and resistant, light-gray to white to pale yellow (2.5 Y 7/2 to 2.5 Y 8/2 to 5Y 8/3) and locally red to brick red to brown due to iron oxidation. The sandstone is non-calcareous, clean and quartz-rich, medium- to fine-grained, with a few to 10% of black and white chart. The bedding is medium to thick and parallel. Bioturbation in the form of borings and filled burrows is common, as are symmetrical anastomosing ripple marks on bedding surfaces. 0–30 m thick.

Short—

Gray to brown sandstone, shale, mudstone and impure coal. Lowermost sandstones are light-gray to grayish-brown and clay-rich and grade into very dark-gray to brown sandy mudstones and shaley sandstones. Gray to brown fissile shale and thin-bedded black impure coal are present. Prominent upper sandstones beds are gray to white to red where oxidized, quartzose, and resistant, with medium to thick parallel beds. These are highly variable in thickness and may be absent. 0–30 m thick.

Mancos Shale

Kmmu Mulatto Tongue of the Mancos Shale

Late Cretaceous

Long—

Relatively sandy marine shale displaying a distinctive yellowish color and eroding readily to produce subdued topography. Local 1–4 m thick sandstone tongues (fine-lower- to fine-upper-grained) in the upper 15 m of the unit. The bulk of the unit consists of laminations to very thin beds that are horizontal-planar to slightly wavy (up to 2 cm amplitude). The sand may be in thin, tabular beds or exhibit hummocky cross-stratification (locally ripple-marked). There are sharp contacts between beds. The sediment consists of very fine- to fine-grained sandstone and siltstone interbedded with subequal to subordinate proportions of fissile shale or claystone. The shale and claystone are pale-brown to light-yellowish-brown or brown to dark-grayish-brown (10YR 5–6/3–4; 10YR 4/2; 2.5Y 6/1–4; 2.5Y 5/2; 2.5Y 4–5/3). The sand is pale-brown to white (2.5Y 7/3–4; 2.5–10YR 6/3; 2.5Y 8/2–3; 2.5–5Y 8/1) or light-gray to very pale-brown (10YR 7/3–4; 2.5Y–10YR 7/2), mostly very fine-lower to fine-lower, subangular, well-sorted, and composed of quartz, ≈3% feldspar, and 5% mafic and lesser lithic grains. Local detrital matter is present, especially coal that is mostly <1 mm but locally up to 4 mm. 5% of the strata consist of lenticular to tabular, thin to medium beds of light-gray sandstone that are internally horizontal-planar-laminated or cross-laminated (including hummocky cross-lamination). North of Cañoncito, laminated to thin-bedded, medium- to fine-grained, light-gray to pale-brown (10 YR 6/1–6/3) calcareous sandstone beds of the Juana Lopez Member form low, distinct ridges in the shale outcrop belt. These beds contain abundant trace fossils, burrows, and fossil hash of bivalves. The Juana Lopez beds become indistinct to the south. Trace to 1% laminae to very thin beds of crystalline gypsum are probably a product of diagenesis or groundwater precipitation. Locally, paleo-burrows are present (1–2 mm wide). Moderately to well-consolidated. Thickness is 75–100 m

Short—

Yellowish, sandy marine strata consisting of very fine- to fine-grained calcareous sandstone and siltstone interbedded with subequal to subordinate shale and claystone. The strata are laminated to very thinly bedded, horizontal-planar to slightly wavy to (in the sand) hummocky rippled. There are 5% lenticular to tabular, thin to medium beds of light-gray sandstone. Thin-bedded to

laminated fossiliferous sandstone of the Juana Lopez Member is present north of Cañoncito. Trace to 1% lamina to very thin beds of gypsum. 75–100 m thick.

Kmmi Middle Part of Mancos Shale between the Gallup Sandstone and Twowells Sandstone Tongue of the Dakota Sandstone

Late Cretaceous

Long—

Poorly exposed shale. Dark-gray to light-yellowish-brown to pale-brown fissile mudstone (clay>silt) and silty shale in laminated to very thin, tabular to slightly wavy beds (<1 cm of relief). Local gray and greenish colors. The upper 1 m consists of interbedded shale and very fine- to fine-grained sandstone, representing a gradational zone with the overlying Gallup Sandstone (**Kg**); below this transitional zone lies very fine-sandy shale. Sparse boulder-size concretions cemented by calcium carbonate and lesser silica are present. 160–180 m thick.

Short—

Poorly exposed, gray to light-yellowish-brown to pale-brown, fissile mudstone (clay>silt) and shale in laminated to very thin, tabular to slightly wavy beds (<1 cm of relief). Local gray and greenish colors. The upper 1 m grades into the overlying Gallup Sandstone (**Kg**), below this transition lies very fine-sandy shale. Sparse boulder-size concretions cemented by CaCO3. 160–180 m thick.

Kmwdt Whitewater Arroyo Tongue of the Mancos Shale and Twowells Member of the Dakota Sandstone, undivided

Late Cretaceous

Long—

Cross-section only. See individual descriptions of **Kmw** and **Kdt**.

Short—

Cross-section only. See individual descriptions of **Kmw** and **Kdt**.

Kmw Whitewater Arroyo Tongue of the Mancos Shale

Late Cretaceous

Long—

Poorly exposed dark-grayish-brown to light-gray, fissile shale and yellowish-brown to very pale-brown, massive silty shale. 18–25 m thick.

Short—

Poorly exposed dark-grayish-brown to light-gray, fissile shale and yellowish-brown to very pale-brown, massive silty shale. 18–25 m thick.

Kmcdc Clay Mesa Tongue of the Mancos Shale and Cubero Member of the Dakota Sandstone, undivided

Late Cretaceous

Long—

Mapped in areas where the two units cannot be illustrated separately at the scale of the map. See individual descriptions of **Kmcm** and **Kdc**.

Short—

Mapped in areas where the two units cannot be illustrated separately at the scale of the map. See individual descriptions of **Kmcm** and **Kdc**.

Kmcm Clay Mesa Tongue of Mancos Shale

Late Cretaceous

Long—

Light- to dark-gray to very pale-brown, parallel and very thin- to thin-bedded, fissile shale and silty shale with thin limestone layers and concretions. The unit becomes more silty and sandy upwards as it grades into the overlying Paguate Sandstone Tongue (**Kdp**). It is usually poorly exposed and covered by colluvium and rubble of the Paguate Sandstone Tongue, except in vertical cliffs. 10–15 m thick.

Short—

Light- to dark-gray to very pale-brown, parallel and very thin- to thin-bedded, fissile shale and silty shale with thin limestone layers and concretions. The unit becomes more silty and sandy upwards as it grades into the overlying Paguate Sandstone Tongue (**Kdp**). It is usually poorly exposed and covered by colluvium and rubble of the Paguate Sandstone Tongue, except in vertical cliffs. 10–15 m thick.

Kg Gallup Sandstone

Late Cretaceous

Long—

Cliff-forming quartz sandstone. The lower portion forms a ledge or cliff and is calcareous, fine- to medium-grained, but locally coarse to very coarse, pale-tan to medium-reddish-brown quartz sandstone with a few percent of dark mafic minerals and/or chert. Grains are subangular to

subrounded. Parallel, medium- to very thick-bedded to cross-bedded with multi-directional troughs. In coarse, trough cross-bedded areas, white chert and dark mafic minerals and lithic fragments(?) may be 15–20% of the rock. The upper portion weathers back from cliff edge and is white to pale-gray. It is composed of friable fine- to medium-grained poorly-sorted, non-calcareous quartz sandstone with a few percent of pink, white, and black chert grains. Medium- to thick-bedded with broad, multi-directional trough cross-beds. The unit weathers into distinctive "beehive" domes. 35–40 m thick.

Short—

Lower, ledge-forming, calcareous, quartzose sandstone that is fine- to medium-grained (locally coarse to very coarse) and pale-tan to reddish-brown, medium to very thick, tabular bedded and trough cross-bedded. Upper non-cliff-forming, white to pale-gray, composed of friable, fine- to coarse-grained, non-calcareous quartzose sandstone that is trough cross-bedded. 35–40 m thick.

Dakota Sandstone

Kdt Twowells Sandstone Member of the Dakota Sandstone

Late Cretaceous

Long—

Shaley sandstone coarsening-upward to clean sandstone. The lowermost beds are a medium-gray, fine-to medium-grained, non-calcareous, quartz sandstone with clay matrix and are gradational into the underlying Whitewater Arroyo Shale Tongue (**Kmw**). The thin- to medium-thickness beds are parallel. A silty and shaley interval separates these from the uppermost beds, which are light-gray to pale-brown, fine- to coarse-grained, moderately well-sorted noncalcareous quartz sandstone with several percent of lithic fragments, mafic mineral grains, chert, and dark-green to black glauconite, which is distinctive of the unit. The upper beds are thin to very thick with planar cross-beds prominent locally. 5–15 m thick.

Short—

Coarsening-upward shaley sandstone and sandstone. Lowermost beds: gray, fine-to medium-grained, non-calcareous, quartz sandstone with a clay matrix; lenses of dark shale a few cm-thick; thin to medium, tabular beds. Uppermost beds: light-gray to pale-brown, fine- to medium-grained, quartzose sandstone; thin- to medium-bedded with prominent local cross-bedding (planar foresets). Glauconite is present and distinctive. 5–15 m thick.

Kdu Paguate Member of the Dakota Sandstone, Clay Mesa Tongue of Mancos Shale, Cubero Member of the Dakota Sandstone, and Oak Canyon Member of the Dakota Sandstone, undivided

Late Cretaceous

Long—

Cross-section only. See individual descriptions of **Kdp**, **Kmcm**, **Kdc**, and **Kdoc**.

Short—

Cross-section only. See individual descriptions of **Kdp**, **Kmcm**, **Kdc**, and **Kdoc**.

Kdp Paguate Sandstone Member of the Dakota Sandstone

Late Cretaceous

Long—

Massive, cliff-forming clean quartz sandstone. White to pale-tan, fine- to locally very fine-grained clean quartz sandstone. Grains are rounded to well-rounded. The unit often has little discernible bedding and is thus massive in appearance. Medium-brown filled burrows and round to oval concretions are abundant. The unit generally makes a bold cliff and abundant blocky rubble with boulders up to 10 m in diameter. In most areas a distinctive clean quartz sandstone upper layer is present, 0.5–1 m thick, that is lighter in color to white, not calcareous, well-bedded, and has well-developed, regular joints. The main body of the unit has irregular, less abundant joints. The base of the unit is usually somewhat gradational with the underlying shale; upper contact is sharp. 6–15 m thick.

Short—

Massive, cliff-forming sandstone composed of white to pale-tan, fine-grained (locally very fine-grained), clean, quartzose sandstone. Abundant paleo-burrows and concretions are present. The base of the unit is usually somewhat gradational, but the upper contact is sharp. 6–15 m thick.

Kdc Cubero Sandstone Member of the Dakota Sandstone

Late Cretaceous

Long—

White to medium gray ledge-forming noncalcareous sandstone composed of well-sorted and subangular to subrounded quartz grains with less than 5% black and white grains of probable chert; parallel- and thin- to medium-bedded. Bedding surfaces commonly display abundant filled burrows as well as a consistent joint pattern that forms lozenges or diamonds. The lower contact is gradational with underlying shales of the Oak Canyon Member (**Kdoc**); the upper contact is sharp. Variable in thickness, generally about ≈10 m thick.

Short—

White to medium gray ledge-forming sandstone composed of non-calcareous quartzose sandstone; parallel- and thin-bedded to medium-bedded. The lower contact is gradational with **Kdoc**, the upper contact is sharp. ≈10 m thick.

Kdoc Oak Canyon Member of the Dakota Sandstone

Late Cretaceous

Long—

Ledge-forming brown sandstone overlain by shale and probable siltstone beds. The basal sandstone is usually 1–2 meters thick, pale-brown, brownish-yellow, and dark-yellowish-brown, quartzose, and not calcareous. One thick to three distinct but thinner beds may be present due to lateral facies variations. Bedding is generally flat with local zones of cross-bedding between parallel beds. Quartz grains are medium- to coarse-grained and subrounded to well-rounded. A few percent of varicolored chert grains are present. Symmetric ripples are present on some bedding surfaces and pits, and tubules are abundant, indicative of bioturbation. The sandstone forms a distinct brown ledge above underlying cliffs and rubbly slopes of Jurassic rocks. The upper Oak Canyon Member comprises about half of the unit and is a poorly exposed shale with probable siltstone and bentonite beds. The shale is usually significantly weathered back from the basal sandstone ledge and forms rubble-covered, vegetated slopes below the overlying Cubero Sandstone Member. 18–23 m thick.

Short—

Ledge-forming brown sandstone overlain by poorly exposed shale and probable siltstone beds. The basal sandstone is usually 1–2 meters thick, pale-brown, brownish-yellow, and dark-yellowish-brown, quartzose, and not calcareous. One thick to three distinct but thinner beds may be present due to lateral facies variations. The shale is usually significantly weathered back from the basal sandstone ledge and forms rubble-covered slopes. 18–23 m thick.

LATE JURASSIC

Morrison Formation

Jmbb Brushy Basin Member of the Morrison Formation

Late Jurassic

Long—

Slope-forming mudstone and lensoidal fluvial sandstone. Mudstone is bentonitic and light-greenish-gray, reddish-gray and weak-red with abundant calcareous nodules 5 to 10 cm in diameter. The surface is characterized by crumbly “popcorn” weathering texture due to high content of swelling clay minerals. Mudstone intervals are often obscured by blocky sandstone

colluvium derived from overlying units and/or sandstone interbeds. The sandstones are medium- to coarse- to very coarse-grained, locally pebbly, white, yellow, pale-brown and darker-colored, noncalcareous, and highly variable in degree of cementation. They represent intermittent deposition of sand in channels in a dominantly floodplain or lacustrine environment. ≈60–75 m thick.

Short—

Slope-forming green, red, and gray bentonitic mudstone and medium- to coarse-grained pebbly cross-bedded fluvial sandstone. ≈60–75 m thick.

Jmsw Salt Wash Member of the Morrison Formation

Late Jurassic

Long—

Moderately friable pale-yellow to pale-olive (5Y 7/4 to 5Y 6/3) medium- to coarse-grained sandstone with broad trough cross-beds to locally massive internal structure with no distinct bedding. The unit only occurs in the southwest corner of the quadrangle and thins out to the north. 0–25 m thick.

Short—

Moderately friable pale-yellow to pale-olive (5Y 7/4 to 5Y 6/3) medium- to coarse-grained sandstone with broad trough cross-beds to locally massive internal structure with no distinct bedding. The unit only occurs in the southwest corner of the quadrangle and thins out to the north. 0–25 m thick.

Jbs Bluff Sandstone and Summerville Formation, undivided

Late Jurassic

Long—

Cross-section only. See individual descriptions of **Jb** and **Js**.

Short—

Cross-section only. See individual descriptions of **Jb** and **Js**.

Jb Bluff Sandstone

Late Jurassic

Long—

Red to banded red and white quartz sandstone. Fine- to medium-grained, slightly calcareous quartz sandstone with a fine-grained to silty matrix. Color ranges from red (2.5 YR 5/6) to dark-

red (10 R 5/6) with prominent white bands. Broad planar tabular cross-beds are several meters high with bases tangential into subparallel very thick beds. The unit forms very distinct cliffs with a rounded top. The top few meters of the unit are usually bleached white. Base not exposed; 60 m thick on Arch Mesa quadrangle to the west (Moench and Puffet, 1963).

Short—

Red and banded red and white slightly calcareous quartz sandstone. Outcrops form a distinct cliff with a rounded top. 60 m thick.

Js Summerville Formation

Late Jurassic

Long—

Slope-forming unit dominated by mudstone with lesser amounts of fine-grained sandstone and siltstone. Unit usually partly covered by rubble and colluvium derived from overlying Bluff Sandstone. The unit is uniformly reddish-brown (2.5 YR 4/4/) except where reduced to gray colors (2.5 YR N5/N6). The mudstone weathers in angular chunks, locally surface forms distinctive "popcorn" texture due to expanding clays. The base is not exposed; up to 27 m thick on Mesa Gigante quadrangle to the southwest (Moench and Puffet, 1963).

Short—

Slope-forming, reddish-brown, mudstone and lesser fine sandstone and siltstone, often covered with rubble and colluvium. 27 m thick.

Jt Todilto Formation

Late Jurassic

Long—

White to light-gray (5–7.5 YR N8/1 to 5–7.5 YR N 7) sugary-textured gypsum with "chicken-wire" structures. Outcrops in irregular mounds and domes. Base not exposed; 18 to 27 m thick on Mesa Gigante quadrangle to the southwest (Moench and Puffet, 1963).

Short—

White to light-gray gypsum. 18–27 m thick.

Je Entrada Formation

Late Jurassic

Long—

Cross-section only. Sandstone and siltstone. 61 m thick.

Short—

Cross-section only. Sandstone and siltstone. 61 m thick.

TRIASSIC AND PERMIAN

TRc Chinle Formation

Triassic

Long—

Cross-section only. Mudstone, siltstone, and channel sandstone. 460 m thick.

Short—

Cross-section only. Mudstone, siltstone, and channel sandstone. 460 m thick.

TRPu Agua Zarca Sandstone Member of the Chinle Formation and Moenkopi Formation, San Andres Limestone, Glorieta Sandstone, and upper part of the Yeso Formation, undivided

Triassic and Permian

Long—

Cross-section only. Sandstone, siltstone, mudstone, limestone, shale, and gypsum. Contains multiple unconformities. 210 m thick.

Short—

Cross-section only. Sandstone, siltstone, mudstone, limestone, shale, and gypsum. Contains multiple unconformities. 210 m thick.

PERMIAN

Pym Meseta Blanca Sandstone Member of the Yeso Formation

Permian

Long—

Cross-section only. Siltstone and sandstone. 174 m thick.

Short—

Cross-section only. Siltstone and sandstone. 174 m thick.

Pa Abo Formation

Permian

Long—

Cross-section only. Mudstone and arkosic sandstone 162 m thick.

Short—

Cross-section only. Mudstone and arkosic sandstone 162 m thick.

PENNSYLVANIAN

IPms Madera Group and Sandia Formation, undivided

Pennsylvanian

Long—

Cross-section only. Limestone, shale, arkosic limestone, and sandstone. 380 m thick.

Short—

Cross-section only. Limestone, shale, arkosic limestone, and sandstone. 380 m thick.

PROTEROZOIC

XY Igneous and metamorphic rocks

Proterozoic

Long—

Cross-section only. Igneous and metamorphic rocks.

Short—

Cross-section only. Igneous and metamorphic rocks.

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